ETHYLENE ACCUMULATION IN SOUTHEASTERN COASTAL PLAIN SOILS;
SOIL CHARACTERISTICS AND OXIDATIVE-REDUCTIVE INVOLVEMENT[1]

KEY WORDS: Soil-ethylene, organic matter, pH, nitrate content,
soil matric potential

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ABSTRACT

Two laboratory experiments were conducted to assess the
extent of ethylene production in southeastern Coastal Plain soils;
the influence of soil characteristics on ethylene accumulation;
and the impact of oxidative, reductive, and oxidative-reductive
interactive conditions upon ethylene formation. Soils from 21
sites over 9 selected soil series typical of the Coastal Plain
physiographic region were air dried, sieved, incubated at 25°C
with 50 mb matric potential or saturated soil water contents, and
analyzed for ethylene accumulation. Soil nitrate, organic matter,
and pH vs. ethylene accumulation were statistically evaluated by a
quadratic surface response curve; a R^2 of 0.77 was obtained. In
the second study, an oxidative-reductive interactive vat system
was used to investigate the involvement of oxidative, reductive,

and oxidative-reductive conditions. Ethylene was found to accumu-
late under both oxidative and reductive conditions; however, the
mixing of oxidative and reductive solutions did not increase the
accumulation of ethylene.

INTRODUCTION

Ethylene production in soils has been an area of considerable
interest to researchers around the world for over ten years (Smith
and Russel, 1969; Eplee, 1975; Hunt et al., 1980a). Ethylene is a
plant hormone and is known to cause plant physiological responses
such as epinastic growth of tomato at >2ppm concentration in the
soil (Jackson and Campbell, 1975), and it has considerable poten-
tial importance in soil systems. Yet, the actual mode of C_2H_4
production in the soil and the conditions under which it is formed
are not agreed upon. Nitrate has been reported to suppress C_2H_4
production (Smith et al., 1976; Hunt et al., 1980a). Goodlass and
Smith, (1978), however, reported only very high concentration of
nitrate affected C_2H_4 production in the soils they investigated.
Hunt et al. (1980a) proposed that this difference could be related
to physiochemical differences involving soil pH, Eh, Fe, and Mn.

Some authors believe C_2H_4 is produced under aerobic condi-
tions (Lynch, 1975; Primrose, 1976), while others believe it to be
produced anaerobically (Smith and Cook, 1974). Hunt et al. (1980a)
proposed that C_2H_4 production in a Norfolk sandy loam soil may
occur under both aerobic and anaerobic conditions. They found
that aerobic accumulation of C_2H_4 was enhanced greatly by methio-
nine, but anaerobic accumulation was affected very little by

methionine. The existence of the two processes would explain a
considerable amount of disagreement in the literature concerning
whether C_2H_4 production was an aerobic process or anaerobic pro-
cess. However, an interactive oxidative-reductive process as sug-
gested by Lynch (1975) cannot be excluded. The substrate for
aerobic production of C_2H_4 could be produced under anaerobic
conditions, but utilized for C_2H_4 production under aerobic condi-
tions. A similar but reversed process is well documented for the
interaction of oxidative and reductive conditions in nitrification
and denitrification in wetland environments (Patrick and Mikkel-
sen, 1971).

This laboratory study was conducted to 1) assess the extent
of C_2H_4 production in southeastern Coastal Plain soils, 2) assess
the influence of soil characteristics on C_2H_4 accumulation, and 3)
assess the impact of oxidative, reductive, and oxidative-reductive
interactive conditions upon C_2H_4 formation.

METHODS AND MATERIALS

Experiment I

A study was conducted with soil from 21 sites over 9 selected
soil series typical of the Coastal Plain physiographic region.
The soils were air dried and sieved through a 10 mesh sieve. They
were analyzed for nitrate by copper sulphate extraction and spe-
cific ion electrode analysis (Lewis, 1961). The organic matter
content was determined by weight loss ignition (Jackson, 1958),
and pH was determined on a one to one soil to water suspension
(W/V). Soil water content at 50 mb matric potential was deter-

mined on disturbed cores by the method described by Richards
(1948). Saturation was considered to be the moisture content at
which a sheen was left after pulling a spatula across the soil
surface. Bulk density was determined by the core method. Proper-
ties of the soils are reported in Table 1.

Triplicate, twenty gram samples of each soil were placed in
37 ml glass bottles, sealed with rubber septum and incubated at
25°C. One set was incubated at 50 mb matric potential and one set
was incubated under saturated water conditions. They were sampled
by use of gas tight syringes for O_2 and C_2H_4 on days 0, 1, 2, 5,
9, 14, and 15 and days 0, 3, 7, 12, 17, and 21 for the 50 mb and

TABLE 1

Soil Characteristics and Maximum C_2H_4 Accumulation

OBS No.	Soil Series	Organic Matter %	pH	$[NO_3]$ ppm	$[C_2H_4,max]$ ppm
1	Coxville	3.34	5.4	4.19	0.27
2	Dunbar	3.03	5.1	4.36	0.93
3	Duplin	2.44	5.6	1.32	1.31
4	Duplin	3.25	5.7	2.97	5.33
5	Goldsboro	2.11	5.4	2.23	0.93
6	Goldsboro	1.71	5.7	2.03	1.30
7	Portsmouth	1.70	5.5	1.76	1.15
8	Norfolk	1.53	5.8	2.46	1.22
9	Norfolk	1.07	6.1	3.27	0.27
10	Norfolk	1.38	6.1	1.32	2.07
11	Rains	3.10	5.5	2.70	2.84
12	Rains	2.05	5.7	1.60	2.10
13	Rains	2.27	5.7	4.79	0.83
14	Troup	0.70	5.9	1.09	1.02
15	Troup	0.81	6.2	1.66	2.06
16	Wagram	0.71	5.8	1.32	1.02
17	Wagram	1.19	6.1	1.32	0.17
18	Wagram	0.72	6.1	1.85	0.25
19	Wagram	1.21	6.3	3.78	0.93
20	Wagram	1.13	5.9	2.84	0.27
21	Wagram	0.69	5.8	1.39	2.27

saturation treatments, respectively. Ethylene concentrations were determined on a Hewlett Packard 5750 gas chromatograph equipped with a flame ionization detector and an aluminia F column at 100°C. Oxygen was determined by use of a Cd–Au electrode. The maximum C_2H_4 accumulation vs. soil nitrate, organic matter, and pH relationship was analyzed by a quadratic surface response curve.

Experiment II

An oxidative–reductive interactive reaction vat system as reported by Hunt et al., (1980b) was used. The system is a modification of the reaction vat system reported by Patrick et al., (1973) for studies of physicochemical processes under varying oxidative–reductive conditions. It allowed gas samples from oxidized and reduced soil suspensions to be obtained, and it allowed the liquid phase of the two systems to be interchanged. A Norfolk sandy loam (Typic paleudult) containing 75% sand, 22% silt, and 3% clay was passed through a 200 mesh sieve. Its pH was 5.2, and its organic matter content was 1.3%. Two hundred grams of the sieved soil and 1g of ground bermudagrass (Cynodon dactylon L.) were suspended in 2.5 liters of distilled water by a magnetic stirrer. The gas space above the suspensions of one vat contained air and the gas space above the other contained N_2. These atmospheres were replaced daily to maintain distinct oxidized and reduced conditions. Duplicate oxidative–reductive systems were used. The gas spaces were sampled for O_2 and C_2H_4. James solid state pH electrodes were used to measure pH. A calomel and a bright platinum electrode were used for measuring Eh. The liquid contents of the oxidative and reductive vats were interchanged

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after distinctly oxidized and reduced conditions had developed. The liquid phases were interchanged for about 10 min/24 h, which allowed for approximately 10% of the contents to be interchanged each day. In separate experiments, either 10 or 30 ppm of C_2H_4 was added to the air space of the oxidized and reduced vats, and C_2H_4 was monitored.

RESULTS AND DISCUSSION

Experiment I

The maximum C_2H_4 accumulation for the soils incubated at 50 mb matric potential was less than the maximum C_2H_4 accumulation in the same soils incubated at saturation (Fig. 1). This is in agreement with data of Hunt et al. (1980a), where significant C_2H_4 accumulation only occurred at water contents very close to saturation. This indicates that C_2H_4 accumulation potential in many soils of the southeastern Coastal Plain physiographic region is similar to that of many soils of the world as related to high soil water and low soil O_2 concentrations. The average maximum accumulation was on day 7. However, it must be remembered that both production and consumption of C_2H_4 are involved in accumulations. We have found accumulation increases followed by concentration declines to be common.

Data in Table 1 shows that these soils accumulated a maximum and a minimum of 5.33 and 0.17 ppm, respectively, under saturated conditions. Thus, all of the tested soils produced some C_2H_4, and more than one-half of the soils tested accumulated more than 1.0 ppm. On part per million in these bottles equals 2.2 ng C_2H_4/g of
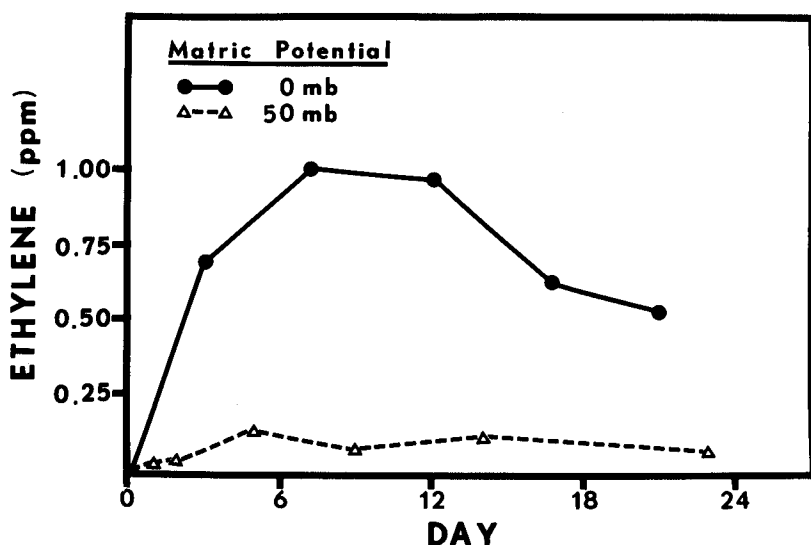
FIG. 1   Ethylene accumulation under variable matric potential.

soil.   This level of C_2H_4 production could lead to damage of
sensitive crops grown on these soils (Jackson et al., 1975, 1976,
1978).

　　　Maximum C_2H_4 production was correlated to soil organic matter,
nitrate concentration and pH with a quadradic surface response; an
R^2 of 0.77 was obtained (equation 1).

$$C_2H_4 = 487.40 - 71.41(O.M.) - 154.78 \ (pH) \qquad [1]$$
$$+ \ 14.75 \ (NO_3) + 11.53 \ (O.M. \times pH)$$
$$- \ 0.84 \ (O.M. \times NO_3) - 2.28 \ (pH \times NO_3)$$
$$+ \ 2.21 \ (O.M.)^2 + 12.27 \ (pH)^2 - 0.05 \ (NO_3)^2$$

C_2H_4 = maximum ethylene, ppm

O.M. = organic matter, % (0.5 to 3.5)

NO_3 = nitrate concentration, ppm (1 to 5.4)

　pH = 5.0 to 6.3

The small R^2 indicates that factors other than those tested were involved. Yet; one such factor, bulk density, which ranged from 1.04 to 1.85 did not improve the R^2 of equation 1. Probably the nature of the organic matter (ease of degradation and chemical composition), iron, and manganese content, and initial microbial populations also affect C_2H_4 accumulation. However, the quadratic surface response analysis gave much better correlation with our data than did simple linear regressions. This analysis suggests why there is disagreement in the literature concerning the response nature of various soils for C_2H_4 accumulation when compared only by simple linear regression (Goodlass, 1978).

Although the data base is too limited to allow use of equation 1 as a broad-based predictor of soil C_2H_4, at lower organic matter contents (< 1.04%), C_2H_4 accumulation increased with lower pH values, and generally increased with increased NO_3 content in the studied range. At higher contents of organic matter (2.5 to 3.5%), C_2H_4 was increased by increased pH and reduced NO_3. The differential nature of C_2H_4 accumulation with high and low organic matter could be interpreted to support the thesis of multiple C_2H_4 production processes.

Experiment II

The Eh of the reduced suspension (Fig. 2) decreased to less than 0 mV within the first 24 hour, and the reduced condition was maintained throughout the experiment. Conversely, the Eh of the oxidized suspension was continuously positive throughout the experiment (>+250 mV). The air space of the oxidized vat was
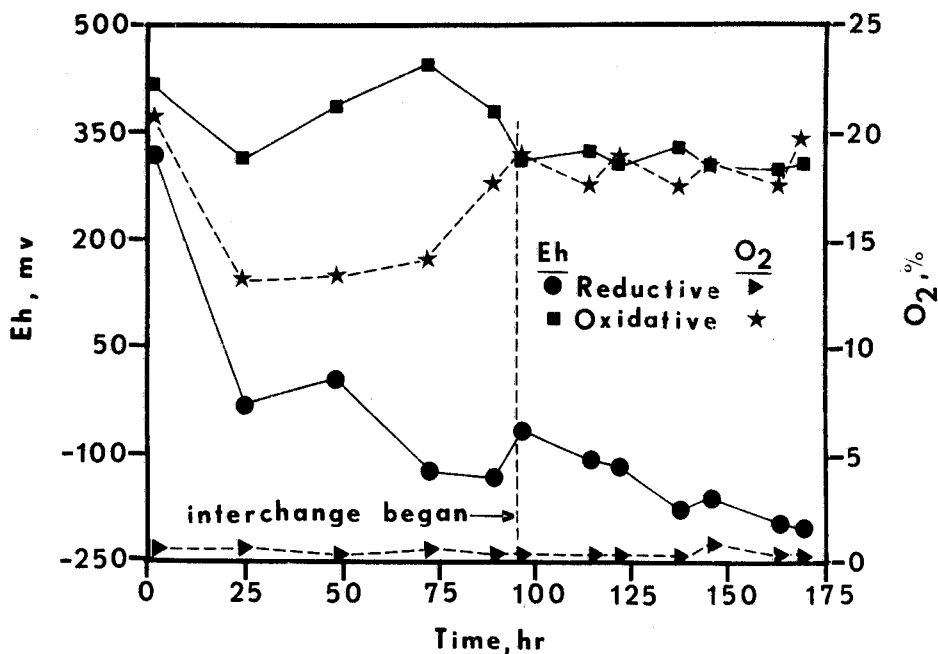
FIG. 2   Eh and O_2 conditions in oxidative and reductive vats before
           and after solution interchange.

maintained above 12% O_2; whereas, it was 0 to 1% in the reduced
vat.   The pH ranged from 6.4 to 7.0.

Figure 3 shows the accumulation of C_2H_4 for each vat over a
7-day period.   The reduced vats were clearly accumulating more
C_2H_4 than were the oxidized vats.   This might be caused by a
greater rate of C_2H_4 degradation under oxidative conditions as
reported by Cornforth (1975).   However, in a separate study when
both 10 and 30 ppm of C_2H_4 were added to the vat head space,
approximately 50% of the C_2H_4 was consumed under either oxidized
or reduced condition.   Similar results were found when the soil
was incubated in small bottles with C_2H_4 added to the air space
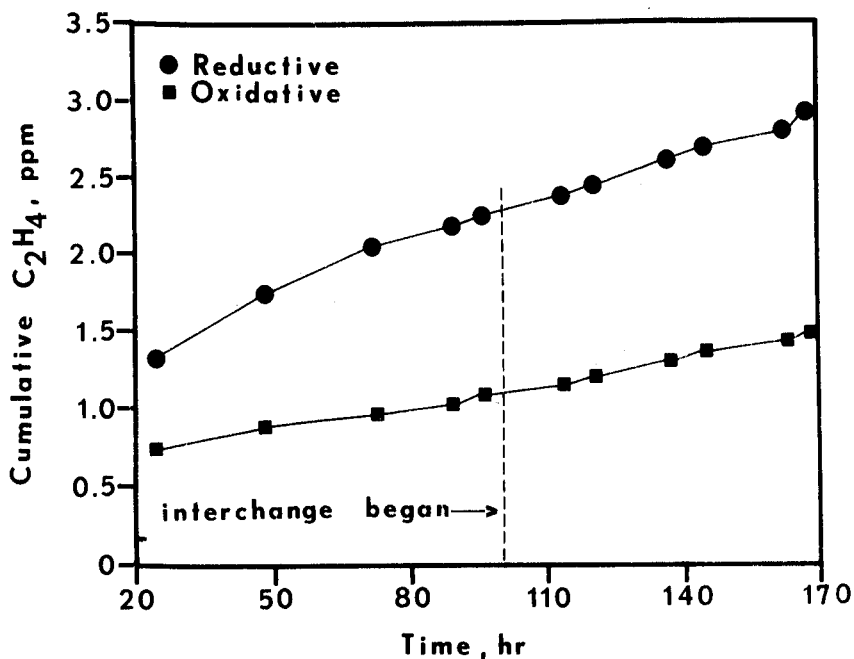
FIG. 3   Ethylene accumulation in oxidative and reductive vats befor
           and after solution interchange.

containing either air or N_2.

    The lack of slope change in the C_2H_4 accumulation curve upon

mixing of the oxidized and reduced liquid phases suggest that the

accumulation of C_2H_4 is not dependent upon or stimulated by the

interaction of substances accumulated under oxidized or reduced

conditions.   Since our mixing method was a batch exchange, we

cannot rule out the involvement of unstable intermediates at the

oxidative-reductive interfaces of the soil.   However, our data

suggest that soil accumulation of C_2H_4 can occur in the Norfolk

loamy sand in either oxidized or reduced microsite without inter-

change.

From these laboratory experiments the authors concluded: 1) C_2H_4 is commonly produced by soils of the southeastern Coastal Plain. 2) The extent of C_2H_4 accumulation was correlated with an R^2 of 0.77 to soil organic matter, pH, and nitrate concentration. 3) C_2H_4 can accumulate under both oxidative and reductive conditions, and it is not greatly stimulated by batch interchange of oxidized or reduced suspension of Norfolk loamy sand. Its occurrence in both oxidized and reduced conditions would support the idea of two independent processes for C_2H_4 production and accumulation in soils. The existence of at least two processes would explain conflicts in the literature concerning whether C_2H_4 is formed aerobically or anaerobically in soils.

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